RF Communication Link for Moon Impact Probe in the Chandrayaan-1 Mission

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***Abstract*—In the Chandrayaan-1 mission, Moon Impact Probe (MIP) was a piggyback payload on the orbiter, with the features of a mini spacecraft. The mission envisaged taking photographs, measuring the altitude and scientific exploration of the moon from near range. During the descent phase to the moon surface, the data is transmitted from the MIP to the orbiter till the Moon Impact Probe is hard landed on the lunar surface. This paper outlines the unique features of the communication system between MIP and Chandrayaan-1, the constraints imposed due to space segment and the steps taken to ensure high reliability of operation under the lunar environment.**

Keywords—Chandrayaan-1, MIP, UHF Link

I. Introduction

Moon Impact Probe (MIP), one of the eleven scientific payloads onboard the Chandrayaan-1, separated from the spacecraft during the final 100 km circular orbit at a predetermined time to impact at a pre-selected location. The mission aimed at collecting and transmitting the scientific and housekeeping data of the probe to the main orbiter (Chandrayaan-1) during the descent phase and subsequent transmission to the ground station.

MIP carried three payloads namely (i) Moon impact Imaging system (MIS) to acquire images of the lunar surface (ii) Radar Altimeter to measure altitude in the final descending phase (iii) Chandra's Altitudinal Composition Explorer (CHACE) to explore the atmospheric composition of the moon surface.

This paper describes the RF Communication system, which provides the communication link between MIP and the main orbiter, from mated condition to impact. This system provides valuable database for future soft landing missions. First section describes the system, such as the frequency selection criteria for the link, acquisition of the probe, link visibility, UHF Transmitter, UHF Receiver and the antennae in detail. Second section deals with the system hardware design. The paper concludes with a detailed discussion of the flight performance in detail and future scopes.

II. System Description

Ultra High Frequency (UHF) telemetry link was used to transmit the data from MIP to the main orbiter. The heart of the communication system consists of UHF Telemetry Transmitter in MIP, which is modulated with the telemetry data, and the UHF Telemetry Receiver in the main orbiter, which demodulates the data. The data is stored in solid-state data recorder for subsequent transfer to Deep Space Network (DSN) using the X Band link of the orbiter. Figure 1 shows the total communication link. Performance of the communication system was monitored through S Band telemetry link.

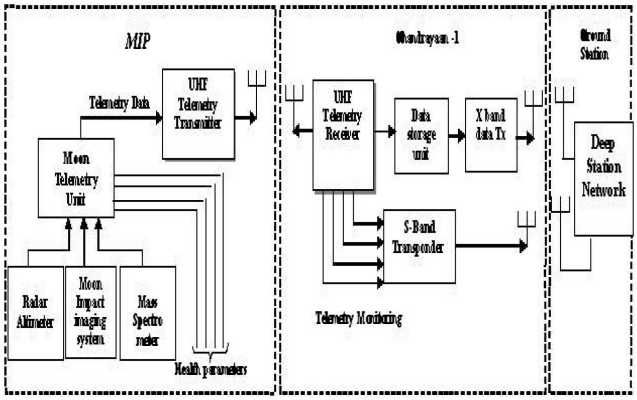

Figure 1. Total Communication Link

III. Frequency Selection Criteria

The technical challenges involved in designing the communication system were

- Acquisition and tracking of the RF link right from separation till impact.
- Communication between two moving satellites.

MIP was spin stabilized during its descent. Due to the weight constraints it was not pragmatic to install high gain or medium gain antenna with the spun system. So the link was designed with two low gain antennae providing a gain of +0dBi and coverage of 60° beam width towards the spin axis. Such communication link should use as low a frequency band as possible to maximize the link capacity by taking advantage of the path loss. However a lower frequency increases the antenna size and hence a trade off is required.

After detailed analysis and studies, the RF link between MIP and spacecraft was selected in the UHF Band. It was

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preferred over S-band due to EMI/EMC compatibility with Chandrayaan-1 payload frequencies. UHF band also has the advantage of less RF power requirement owing to less path loss, less weight and less Doppler shift. A minimized low profile antenna with right circular polarization (RCP) was selected.

The important parameters of the communication system are summarized in Table 1.

TABLE I. SYSTEM PARAMETERS

Transmitter Frequency	402.5 MHz
Power Output	+34dBm
Transmitting antenna	
• Peak gain	+1dBi
• Gain	+0dBi (beam width of ± 30°)
• Polarization	RCP
Orbiter Altitude	100Km-125Km
Receiving antenna	
• Peak gain	+4dBi.
• Gain	+3dBi (beam width of ± 30°)
• Polarization	RCP
Modulation	PCM/Bi-phase/PM
Modulation index	1.5rad max

IV. ACQUISITION OF PROBE AND LINK VISIBILITY

The antenna beam width of the probe and the spacecraft are designed to envelop the position of the other thus satisfying the visibility criteria for communication as shown in figure 2.

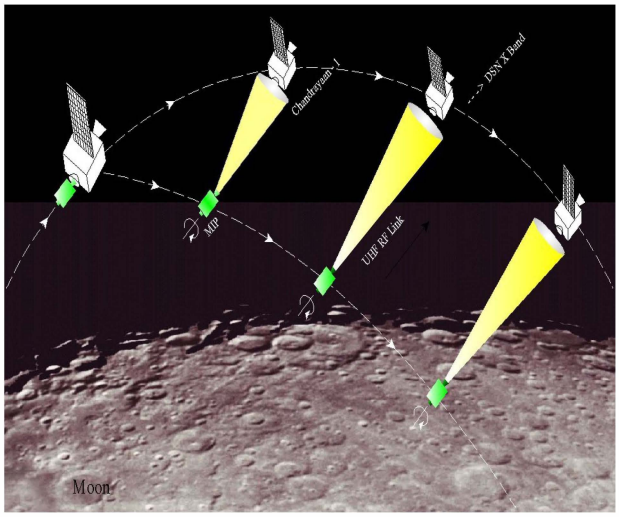

Figure 2. RF Link Scenario

The RF Link has been designed with the following assumptions.

- Unobstructed Line of sight (LOS) between Orbiter antenna and MIP antenna.
- The maximum LOS excursion the communication link can tolerate is ±30°.
- Both the antennae are right circularly polarized.

During the initial acquisition phase, the UHF receiver searches and acquires the carrier transmitted by the probe. Since the probe is spin stabilized, theoretical analysis has been carried out to study the effects of spin dispersions on the communication link and the results are shown in Table II.

TABLE II. SPIN RATE VS HALF CONE ANGLE

Spin rate	Half Cone Angle	Remarks
120rpm	1°	Spin rate variation from 120rpm (max) to 16 rpm (min) is expected
30rpm	5°	
16rpm	8°	

For the link calculation, the antenna gain is taken at beam-width of ±30° whereas the maximum expected LOS excursions due to spinning, variation in the angular rates and relative motion were estimated as ±10°.

V. LINK BUDGET

The RF power output of UHF Transmitter is chosen to give the link margins as shown in Table III. Link margins available for various slant ranges are tabulated below.

TABLE III. TYPICAL LINK BUDGET

Slant range (Km)	105	125	130
Carrier link margin (dB) for CNR of -15 dB	22.76	21.86	21.56
Signal Link Margin (dB) for SNR of +12dB	6.92	6.02	5.72

VI. UHF TRANSMITTER

It is a fixed frequency Phase Modulated (PM) transmitter at 402.5MHz with a frequency stability of ±0.003% providing a minimum output power of 2.5W. The basic source of the transmitter is a low frequency crystal controlled oscillator. After PM modulation it is multiplied and filtered to get the required harmonic. The output is amplified to the required power level. An isolator is provided at the output to take care of the load mismatches. It houses an EMI filter to take care of the EMI as per MILSTD 461/462. It also has a DC/DC

converter to provide the required stable DC supply with better efficiency. Fig 3 shows the block diagram of the transmitter.

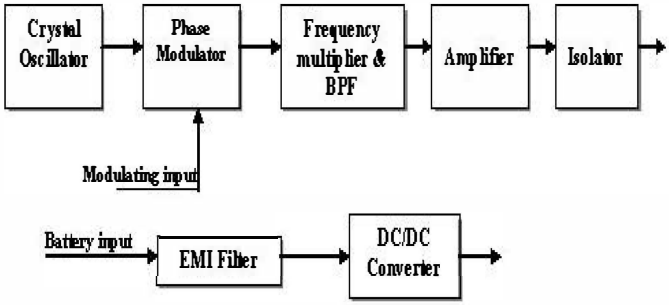

Figure 3. Block Diagram of Transmitter

VII. UHF Receiver

It is a fixed tuned single super-heterodyne receiver. The signal received is sufficiently amplified, filtered and down converted to IF by single conversion. Proper gain distribution and usage of appropriate LNA, RF/IF limiters and filters are provided to achieve the wide dynamic range. Local oscillator is generated using frequency synthesizer technique with VCXO as reference and with sweep aided locking scheme. The Intermediate Frequency (IF) is phase locked to a TCXO and this IF is used for phase demodulation of the telemetry data. System has a tracking sensitivity of –115dBm. The demodulated data is passed through the Bit/ Frame synchronizer. The system also has a built in DC/DC converter and EMI filter to take care of the power supply bus of main

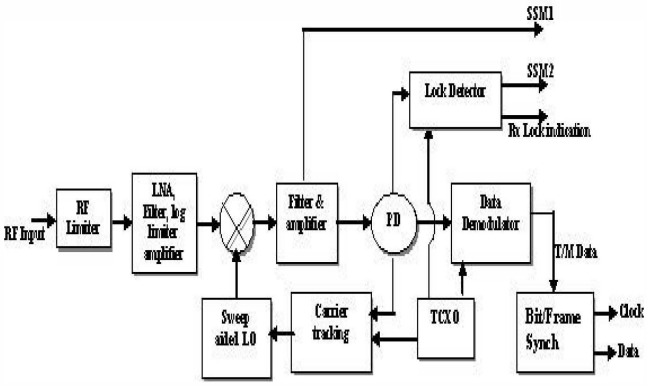

Figure 4. Block Diagram of Receiver

The main constraints imposed on receivers designed for moving platforms are variation in received signal strength and Doppler shift. The UHF receiver is designed to take care of both these factors. The variation in signal strength has been taken care by providing appropriate RF limiters and logarithmic amplifiers. The sweep aided local oscillator with sufficient sweep range takes care of the Doppler shift in the received signal.

VIII. Antennae Type

The visibility of MIP from the main orbiter has to be ensured for smooth data transmission during the descent. The transmitting antenna is located on the orbiter facing side. The line of sight between MIP transmitter antenna and receiver antenna in orbiter has to be within the respective beam width from separation to impact. The antenna is designed to meet the above requirement without reorientation of the spacecraft during the MIP flight.

The transmitting antenna is configured in a turnstile configuration with right circular Polarization (RCP). Four members of inverted-F type antenna elements are fed in equal amplitude and sequential phases. In the receiving end, fractional turn quadrifilar helix (QFH) antenna fed by a sequential power divider is used due to the space limitation in the orbiter. Figure 5 shows the radiation pattern of a antenna.

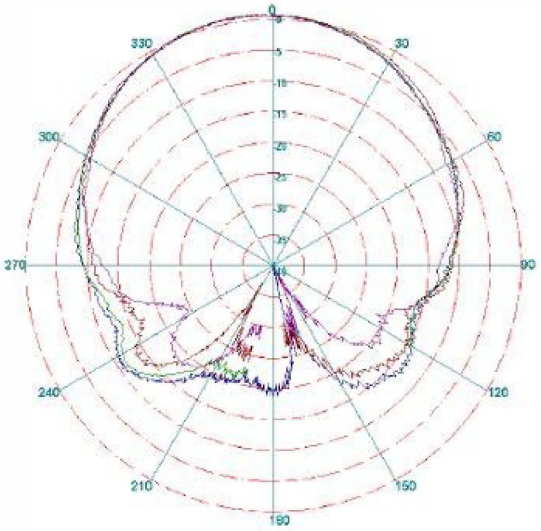

Figure 5. Typical Antenna Radiation Pattern

For moving platforms the antenna coverage is selected to ensure uninterrupted communication between the systems. In this mission, due to the size and weight constraints, low profile antennas with wide beam-width have been selected. Detailed analysis has been carried out to confirm the efficacy of the antenna system in the link performance. More sophisticated techniques such as antenna with steerable beam can provide greater flexibility at the cost of increased system complexity and size.

IX. System Hardware Design

The onboard systems are required to be of low mass, small size, less power consumption. Also the environmental specification requirements are more stringent and demanding. Since no redundancy was planned in MIP, the systems should have high reliability and stable performance in vibration, shock and thermo vacuum environments. To fulfill these requirements, the component selection is important. In this design, MIL 883-B or industrial grade components screened to

MIL level, and having good usage history in various ISRO programmes are used.

Reliability is one of the most important parameter to be considered while designing a space related system. Failure rate of the parts decreases as the margin of safety between the actual stress and rated stress is increased. While designing the circuits, derating of all components was carried out assuming the worst case stress to ensure that it is within the limits specified for the lunar environment.

Thermal management is another most important design criteria considered. The mechanical chassis is made up of aluminum and the external surface is black anodized. Moreover the heat dissipating components are mounted directly on the chassis to take care of the thermal dissipation.

The systems were tested and qualified to MIP/Chandrayaan-1 Environmental Test Levels.

X. Performance In Flight

The communication system maintained carrier lock and provided telemetry data with a SNR greater than 20dB in the mated condition in lunar orbit as well as from separation till impact of the probe without data loss. The UHF receiver has two analog Signal Strength Monitoring (SSM) outputs, which covers linearly the entire dynamic range and a receiver lock detector output. These were monitored at ground through S-Band Transponder in real time. From the signal strength monitoring it is concluded that the link performed as per the prediction. Figure 5 shows the status monitoring data received from the UHF receiver through the S Band telemetry.

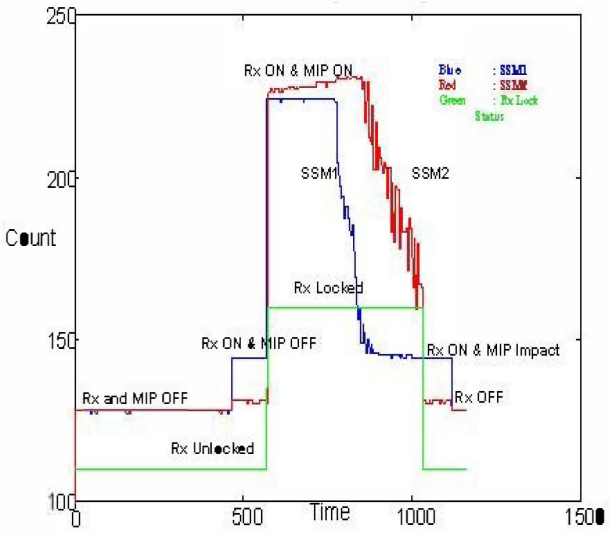

Figure 6. Plots of UHF Receiver status monitoring data

XI. Conclusion

In the Chandrayaan/MIP mission, the design of the communication link is done with minimal subsystems required to achieve the objectives while confirming to the weight and space constraints imposed by the mission. The design, implementation, testing and performance evaluation of the RF communication system for the MIP in the Chandrayaan-1 mission is depicted in this paper. MIP impacted on the lunar surface on 14th November 2008, at 20:31 IST near Shackleton Crater at the South Pole. The Indian tri-color flag was placed on the lunar surface marking India's presence on the moon. The system described here, with minor modifications is able to work as a transponder, for establishing a two-way communication link between the orbiter and lander in the Soft Lander and Human in Space missions. This can be configured as a digital receiver by digitizing from IF onwards which will contribute effectively to enhance the capability of the communication system.

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